THE CAUSE OF BASEMENT FLOODING AT BENT'S OLD FORT NATIONAL HISTORICAL SITE, COLORADO

Scott W. Woods[1]

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August 2002

Final Report for Contract CA 1200-99-009 CSU-23

1. Assistant Professor, University of Montana, School of Forestry, Missoula, Montana 59812. tel. 406-243-5257. e-mail: swoods@forestry.umt.edu.

2. Professor, Colorado State University, Department of Earth Resources, Fort Collins, Colorado 80523. tel. 970-491-6109. e-mail: leemac@cnr.colostate.edu.

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INTRODUCTION

Bent's Old Fort was an important trading post and rest stop for travelers along the Santa Fe trail in the mid-1800s. In recognition of its importance in the settlement of the American West the Fort has been restored, and is now a National Historical Site (NHS) administered by the National Park Service (NPS). In recent years NPS personnel have observed periodic flooding in the basement of the Fort (N. Keohane, National Park Service, pers. comm.). Rotted timbers in the basement of the Fort were replaced in 2000, and concrete bases were placed beneath the new timbers to provide greater support (National Park Service, 2001). However such measures will only provide a temporary solution to the flooding problem, and there is concern about the potential for permanent damage to the Fort's wood and adobe structure. There is an urgent need to determine the cause of the flooding so that a solution can be designed and implemented.

In March 2001 we began a study of the cause of the basement flooding at Bent's Old Fort. The water table in the area around the Fort has risen in recent years (Bossong, 2000). The rising water table has been attributed to a combination of the following factors: 1) a decline in the amount of groundwater being pumped from the aquifer; 2) increased seepage from the Fort Lyon canal; 3) increased deep percolation of irrigation water; and 4) aggradation of the bed of the Arkansas River leading to higher river stage and greater leakage from the river to the alluvial aquifer (Watts and Lindner-Lunsford, 1992; Bossong, 2000). The relative importance of these factors varies with proximity to the Arkansas River, the Fort Lyon Canal, and areas of groundwater pumping and surface irrigation. The purpose of our study was to determine which of these various factors is primarily responsible for causing the periodically high water table levels at Bent's Old Fort.

STUDY SITE

Bent's Old Fort lies adjacent to the Arkansas River, approximately 8 km east of La Junta in southeastern Colorado (Figure 1). The mean annual precipitation at the National Weather Service climate station at La Junta (La Junta 4 NNE) is 29 cm, and the mean monthly precipitation ranges from 0.7 cm in December to 5.1 cm in July (Figure 2). Mean monthly temperatures at La Junta range from –1.3°C in January to 25.6 °C in July.

The flow of the Arkansas River is affected by numerous upstream diversions and the Pueblo Dam. The Pueblo Dam lies approximately 100 km upstream from the Fort and effectively separates this section of the Arkansas River from its headwaters in the Rocky Mountains. The mean annual discharge of the Arkansas River at La Junta (USGS gage no. 07123000) is 7.4 cubic meters per second (m^3/s), and the mean annual peak flow for the period following the closure of the Pueblo Dam in 1974 is 204 m^3/s.

The primary land use in the area surrounding Bent's Old Fort is irrigated agriculture. The irrigation season typically extends from March through September. Irrigation water is obtained primarily from the Fort Lyon Canal, which lies 2.5 km north of the Fort and flows from west to east approximately parallel to the Arkansas River (Figure 1). The diversion point for the Fort Lyon Canal lies approximately 20 km upstream from the Fort. Some irrigation water is also obtained by pumping groundwater from the alluvial aquifer.

The area surrounding the Fort includes several wetlands (Figure 3). The 21-ha Arch wetland lies on the Arkansas River floodplain immediately north of the Fort. NPS personnel report that Arch wetland has gradually increased in extent over the last 15-20 years. The 0.4-ha Casebolt wetland lies approximately 450 m southwest of the Fort in a meander bend of the Arkansas River, and the 0.2-ha Day Pond is located adjacent to the Arkansas River about 300 m southwest of the Fort.

METHODS

Surface water and groundwater hydrology

A network of fifteen monitoring wells was installed on the NPS property surrounding the Fort to monitor groundwater levels (Figure 3). Thirteen of these wells (1-4, 6, and 8-15) were installed in late March 2001. The wells were installed by hand auguring to below the depth of the early season water table, and installing a 1.5-inch diameter Schedule 40 PVC pipe with 0.01-inch factory-slotted screen across the water table. The well borings were backfilled to the surface with native soil. Wells 18 and 19 were installed in mid-May 2001 by driving a steel well point to below the depth of the water table and extending the riser pipe to the surface using 1.5 inch diameter threaded steel pipe. A different method was used to install these wells because they were deeper

than the previous wells. Water levels in all of the wells were measured by NPS personnel approximately weekly from their date of installation until late August 2001.

Electronic water level recorders, comprising a pressure transducer and Omnidata logger, were installed in wells 2 and 10 and programmed to record water levels every 30 minutes from the beginning of June until early September. However, equipment malfunctions meant that continuous data for well 2 were only available from 1 June through 19 July 2001, and for well 10 from 1 June until 9 August 2001. In both cases the 30-minute water levels were averaged to generate daily mean water levels.

Staff gages 7 and 17 were installed on the north bank of the Arkansas River upstream and downstream from the Fort, respectively (Figure 3). Staff gage 5 was installed in the Casebolt wetland southeast of the Fort. Staff gage 16 was installed in the Arch wetland on the north side of the Fort. The staff gages were read by NPS personnel on the same days that well water levels were measured. Provisional daily flow data for the Arkansas River at La Junta (USGS gage no. 07123000) and the Fort Lyon Storage Canal were obtained from the Colorado Division of Water Resources Division 2 office in Pueblo, Colorado.

The horizontal and vertical coordinates for all wells and staff gages were determined by surveying with a total station. The benchmarks for the survey were: 1) a steel survey pin "A-13" located at the northwest corner of the Park's property boundary, by the north side of a gatepost; and 2) a Bureau of Land Management (BLM) brass cap on the west boundary of the park property, approximately 1120 feet south of survey marker A-13 (Figure 3). Coordinates for these points were obtained from the Bent's Old Fort NHS Boundary Survey map dated 10/29/80 (NPS Rocky Mountain Region, Drawing No. 417-41006). The vertical elevation of the BLM monument was set at 100.00 m, and all other elevations are relative to this local datum. The state plane coordinates (Colorado South Zone) for the two benchmarks are as follows:

	Northing (ft)	Easting (ft)
A-13	508204.02	2594650.60
BLM Monument	507087.45	2594675.80

Water quality

Water quality samples were collected from the Arkansas River, Day Pond, Casebolt Wetland Pond, Arch Wetland (2 sites), the NPS maintenance building well, and 3 irrigation return flow ditches along the north side of the NHS property. Samples were collected on two dates (3/27/01 and 7/31/01) but not all sites were sampled on both dates.

The NPS maintenance building well was sampled from the faucet on the outside of the building near the door on the south side. The faucet was allowed to run for approximately 5 minutes to flush the pipe prior to sampling. No samples were collected from the ditches on 27 March because they were all dry. On 31 July tributary ditches 1-4 were not flowing, but tributary 6 and the main irrigation ditch were flowing. Most of the flow at the Main Irrigation Ditch NW site was coming from Tributary ditch #6 when the sample was collected. Water quality sampling sites were located to within approximately 5 m horizontally using a hand-held GPS unit. Field pH values for the March samples were measured the following day due to problems with a field instrument.

The samples were analyzed at the USGS National Water Quality Laboratory (P.O. Box 25046, MS 407, Building 95, Denver Federal Center, Denver, CO 80225-0046), using the methods and procedures of Fishman (1993). Samples were analyzed for the following parameters:

- pH
- temperature
- specific conductance
- turbidity
- Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, Fl^-, SiO_2, SO_4^{2-}
- ANC (acid neutralizing capacity)
- Total dissolved solids
- Nitrogen (dissolved NH_4, total NH_4 + organic, dissolved $NO_3 + NO_2$, dissolved NO_2)
- Phosphorus (dissolved, ortho-phosphorus dissolved).

RESULTS

Surface water hydrology

The daily mean flow of the Arkansas River at La Junta between 1 March and 30 September 2001 ranged from 0.7 m^3/s on 19 April to 36 m^3/s on 16 July (Figure 4), and had a mean of 5.5 m^3/s. The instantaneous annual peak flow for water year (WY) 2001 was 64 m^3/s, and occurred on 16 July. This peak flow was just 31% of the average annual peak flow of the Arkansas River at La Junta for the period since the closure of the Pueblo dam in 1974.

The daily mean flow of the Fort Lyon storage canal between 1 March and 30 September 2001 ranged from 0 to 27 m^3/s (Figure 4) with a mean of 10 m^3/s. There was no flow in the canal prior to 14 March. For the period between 1 March and 30 September 2001, the flow of the Fort Lyon canal exceeded that of the Arkansas River at La Junta on 82% of all days.

The weekly readings at the upstream staff gage (no.7) ranged from a minimum of 90.16 m on 20 April to a maximum of 90.86 m on 18 May, for a total range of 0.70 m (Figure 5). A linear regression between the water levels at staff gage 7 and the corresponding daily mean flows at the USGS gage on the Arkansas River at La Junta was used to estimate the water levels at staff gage 7 in the periods between measurements ($R^2 = 0.67$, standard error = 0.05m). The results of this analysis indicate that between 1 March and 30 September 2001 the stage at staff gage 7 varied by approximately 1.8 m, 1.1 m more than what was indicated by the weekly measurements. The highest estimated stage of 92.1 m, corresponding to the 16 July peak flow, was 1.2 m higher than the highest recorded weekly value.

The weekly readings at the downstream staff gage (no.17) ranged from a minimum of 89.62 m on 20 April to a maximum of 90.53 m on 7 June for a total range of 0.91 m (Figure 5). A linear regression ($R^2 = 0.39$, standard error = 0.09 m) between the weekly readings at staff gage 17 and the corresponding mean daily flows at the USGS gage at La Junta was less useful for predicting water levels in periods between the weekly measurements due to the larger standard error of the regression.

Groundwater hydrology

There was a distinct contrast in the pattern of water level fluctuations between the wells in upland areas (wells 1-3, 6, 13-15, 18, and 19) and those on the Arkansas River floodplain (wells 4 and 8-12). Water levels in most of the upland wells were relatively stable and showed no obvious response to changes in river stage (Figure 6), while water levels in the floodplain wells were more variable and showed a clear response to changes in river stage (Figure 7).

The mean range in water levels in the nine upland wells was only 0.44 m although values varied from a minimum of 0.10 m in well 3 to a maximum of 1.8 m in well 18. However, the large range in water levels in well 18 appears to have been due to a measurement error. If well 18 is omitted, the next highest range in water levels in a upland well is 0.6 m in well 2, and the mean range of water levels for the remaining eight wells was just 0.28 m. There was no clear response in the upland wells to any external factors, such as changes in the flow of the Arkansas River, changes in the flow of the Fort Lyon Canal, or precipitation events. The exception was well 6, which lies on a terrace just 5 meters from the riverbank. Water levels in well 6 responded to changes in river stage. The limited variability and lack of response in water levels in upland wells implies a relatively constant groundwater flux throughout the study period.

No basement flooding was observed at the Fort during the study period. This is consistent with the observed water levels in wells 1, 2 and 3, which indicated that the water table beneath the Fort was consistently about 3 m below the ground surface. In order to encroach into the basement the water table would have to have risen by at least a meter.

For the six wells on the floodplain, the mean total range in water levels was 0.78 m and ranged from 0.6 m in well 8 to 1.3 m in well 10. While the water levels in all of these wells exhibited a clear response to changes in river stage, water levels in all of the wells were consistently higher than the river stage.

Linear regressions were used to determine the strength of the relationship between river stage and the level of the water table in each well. A high correlation and a regression slope close to 1.0 indicate that river stage is controlling the water table level or vice versa. Water levels in most of the upland wells had little or no correlation with river

stage (Figures 8a through 8c, 8l through 8n, 8q and 8r). The only exception was well 6, which had a positive linear relationship between well water levels and river stage (Figure 8f). In contrast water levels in the floodplain wells were highly correlated with river stage (Figures 8d and 8g through 8k). The wells closest to the river and lowest in elevation had the highest correlations (e.g., well 8 in Figure 8g).

Water table maps produced for various dates during the spring and summer of 2001 indicate that groundwater flow was consistently from the upland area west of the Fort towards the Arkansas River (Figures 9, 10 and 11). This indicates that the Arkansas River was gaining flow from groundwater in the reach adjacent to the Fort throughout the study period.

Water level data for all of the wells and staff gages are tabulated in Appendix A.

Wetland Hydrology

Water levels in the Arch wetland were essentially constant except for one measurement on 2 August (Figure 12). Water levels in this wetland were always lower than the water table in wells 13, 14 and 15, indicating that groundwater was flowing into the wetland from the west. Observations in late March 2001 showed that surface water was flowing from Arch wetland into the Arkansas River. By 31 July these surface water outflows had ceased, indicating either that the rate of inflow had decreased, or that evapotranspiration losses were greater than these groundwater inflows.

Water levels in the Casebolt wetland varied from a high of 93.3 m to a low of 92.9 m for a total range of 0.4 m (Figure 13). However, there was no surface water present in the Casebolt wetland after early August. Surface water levels in the Casebolt wetland were consistently about a meter higher than the water table level in well 4, indicating that groundwater inflows were not a source of water for the Casebolt wetland. The highest water levels in the Casebolt wetland corresponded with periods of high surface water irrigation, indicating that this is the primary water source for this wetland.

Surface Water Chemistry

Water quality was generally similar at all of the sites where samples were collected, and similar to values previously reported from nearby sites (Appendix B). In

general, surface water quality was characterized by high turbidity (up to 500 NTUs), high salinity (specific conductance 1200-2200 μS/cm) and high sulfate (466-892 mg/L). Nitrogen concentrations were variable but some sites had moderately high values characteristic of agricultural runoff. The highest value of total dissolved nitrogen was 5.3 mg/L, and this was measured in an irrigation return flow ditch after a thunderstorm. pH values were moderate to high. Moderately high concentrations of trace metals plus high evapotranspiration could cause an increase in the concentration of trace metals in the wetlands with little or no surface water outflows.

DISCUSSION

Previous studies have indicated that the alluvial aquifer of the Arkansas River near La Junta is recharged by percolation of excess surface irrigation, leakage from the Fort Lyon canal, and leakage from the Arkansas River (Watts and Lindner-Lunsford, 1982; Bossong, 2000). The amount of leakage from the Fort Lyon canal increases with increasing stage (Watts and Lindner-Lunsford, 1982). Water is lost from the aquifer via a network of pumping wells used for irrigation, and groundwater discharges to the Arkansas River in gaining reaches (Watts and Lindner-Lunsford, 1982).

The water table level in wells throughout the area between La Junta and Bent's Old Fort has risen and fallen over the last several decades, apparently in response to the relative amounts of recharge and discharge to and from the aquifer. An overall decline in water levels in the 1970s corresponded with a period of reduced flow in the Fort Lyon Canal, reduced surface water applications, and increased groundwater withdrawals. Conversely, a rise in water levels in the 1980s corresponded with a period of increased flow in the Canal, increased surface water applications, and reduced groundwater withdrawals (Bossong, 2000).

Water levels in some lowland wells near the Arkansas River are responsive to changes in river stage. The observed changes in river stage can be due to long-term changes in bed elevation as well as short-term variations in flow. Over the last thirty years groundwater levels have risen gradually in a well near the Arkansas River at La Junta (well no.1 in Bossong, 2000), and the observed increases are similar to the estimated rate of bed aggradation at the USGS gaging station (Bossong, 2000). High

seasonal water table levels in this well are correlated with high streamflow in the Arkansas River, and this relationship is consistent with the fact that water table maps indicate that the Arkansas River is losing flow to groundwater in this reach (see Figure 2 in Bossong, 2000). Water levels in wells adjacent to losing reaches are typically more responsive to variations in stream stage than those adjacent to gaining reaches (Kondolf et al., 1987).

The results of this short-term study, which focused only on the area immediately around Bent's Old Fort, indicate that the Arkansas River was consistently gaining along the reach adjacent to Bent's Old Fort. In other words, since water table levels in the aquifer were higher than the river stage, groundwater was flowing towards the river (see Figures 9, 10 and 11). The implication is that river stage has less of an influence on water table levels along this reach of the river than in the area near La Junta where Bossong (2000) found a strong association between river stage and water table elevations. Although there was often a strong correlation between river stage and water levels in the wells close to the river, the three wells surrounding the fort (1, 2 and 3) showed little correlation with river stage. Hence the primary control on water table levels in the area immediately around Bent's Old Fort is groundwater flux from the adjacent upland. The magnitude of this groundwater flux depends on the amount of recharge from excess irrigation and leakage from the Fort Lyon Canal. Thus, periods of high water table levels in the vicinity of the Fort are likely to be associated with increased seepage from the canal and high rates of surface irrigation.

In the absence of a longer period of record and a more detailed analysis, we cannot evaluate the relative importance of excess irrigation water versus leakage from the Fort Lyon canal for controlling water levels around Bent's Old Fort. However, since the observed groundwater gradients were always from the uplands towards the Arkansas River, the flows in the Fort Lyon canal almost certainly play a role in controlling the water table elevation in the vicinity of the Fort. A proposed change in the allocation of water rights along the Fort Lyon Canal could lead to a substantial decline in flows. One implication of a large decline in flows could be a reduction in seepage from the canal to groundwater, resulting in a drop in water table levels around the Fort.

An important caveat to our results is that this study was conducted during a relatively dry year. The annual peak flow of the Arkansas River at La Junta was just 30% of the long term average. In a year with a higher peak flow the river stage would be substantially higher. This higher river stage could cause a reversal of the groundwater gradient so that water would flow from the river into the aquifer, resulting in increased water table levels around the Fort. This may have been the case in 1999, when flooding was observed in the basement of the Fort. The peak flow of the Arkansas River in 1999 was 850 m^3/s, or more than thirteen times greater than the peak flow observed in 2001. The 1999 peak flow also was twice as large as the next largest peak flow since the closure of the Pueblo dam in 1974. The rating curve for the Arkansas River at La Junta indicates that the stage associated with a peak flow of 850 m^3/s is more than 2.1 m higher than that associated with the peak flow of 64 m^3/s observed in 2001. If this same stage-discharge relationship holds for the reach adjacent to Bent's Old Fort, the peak stage in the Arkansas River in 1999 probably would have been sufficient to reverse the hydraulic gradient. The resulting flow of water away from the river and towards the uplands could have raised the water table level sufficiently to cause the observed basement flooding. Although groundwater flow from the uplands may be the primary control on water levels during relatively low flow years like 2001, high flows in the Arkansas River can also play a direct role in causing basement flooding.

A second effect of high river stage is a reduction in the overall groundwater gradient, and this may hinder the drainage of water seeping from the Fort Lyon canal. In this case the water flooding the basement may be coming from the canal rather than the Arkansas River, but the net effect will be much the same. A more detailed and longer term study of the different water sources and aquifer properties is needed to fully evaluate the effect of the Arkansas River, the Fort Lyon canal and excess irrigation on water table levels and basement flooding at the Fort.

Another concern is the conservation and protection of the wetlands on NPS property. The largest of these, Arch wetland, has increased in size over the last 10-15 years, apparently in response to the local rise in water table levels. The hydrologic data collected in this study show that the primary water source for Arch wetland is groundwater from the adjacent uplands. This conclusion is supported by the similarities

in water chemistry between the groundwater and the surface water in the Arch wetland. The dependence of the Arch wetland on groundwater from the adjacent upland means that a decrease in flow in the Fort Lyon canal could cause a decrease in the size of the Arch wetland. Similarly, an increase in groundwater withdrawals upgradient from the wetland could reduce groundwater inflows and reduce the size of the wetland.

Another concern is the location of the proposed new administration building. The area presently occupied by the visitor center parking lot has been suggested as a potential location for this building. The closest monitoring well to the visitor center parking lot is well 14. In 2001 the water table in this well was within 1.5 meters of the ground surface throughout the summer. The elevation of the ground surface at well 14 is slightly lower than the parking lot elevation, but the depth to the water table in the vicinity of the parking lot is probably similar to that in well 14. Any proposed construction design must consider that the water table is currently at a depth of approximately 1.5 meters below the surface, and could be closer to the surface in years that are wetter than 2001. It should also be noted that there has been an upward trend in water table level in the area near the Fort since the early 1980s (Bossong, 2000).

Future trends will depend on factors such as the amount of water flowing in the Fort Lyon Canal, the amounts of irrigation water obtained from groundwater and surface water respectively, and the bed elevation of the Arkansas River. Given the current upward trend in water table levels, and the potential for water levels to rise substantially in high flow years, it may be prudent to locate the new administration building in an upland area with a deeper water table.

The data collected in 2001 have provided a basic understanding of groundwater gradients and sources of water for the wetlands at Bent's Old Fort NHS. However, a better assessment of the flood risk, the siting of a new administration building and a means to reduce the flood hazard for Bent's Old Fort will require a more detailed evaluation of the groundwater hydrology in the vicinity of the Fort, including groundwater flow rates and the hydraulic conductivity of the geologic materials beneath the Fort. These data should be collected during the spring and summer of 2002. Given the temporal variability in water levels and groundwater flow directions, it is also critical that

the hydrologic monitoring be continued in order to better represent the range of conditions that can occur at Bent's Old Fort NHS.

CONCLUSIONS

1) Under conditions of low to average flow in the Arkansas River, groundwater levels in the vicinity of Bent's Old Fort are controlled primarily by the rate of surface water irrigation and leakage from the Fort Lyon Canal;

2) Under high streamflow conditions, such as those that occurred during the 1999 peak flow, there can be a local reversal of the hydraulic gradient between the alluvial aquifer and the Arkansas River. The flow of water from the river, combined with increased leakage from the Fort Lyon canal, are a likely cause of the high water table levels observed in the vicinity of the Fort, and the consequent basement flooding;

3) Water quality in the vicinity of Bent's Old Fort is characteristic of surface water runoff in agricultural areas, and provides little information in terms of differentiating between water sources;

4) Proposed reductions in the flow rate of the Fort Lyon canal may slow or even reverse the upward trend in water table levels in the vicinity of Bent's Old Fort;

5) The Arch wetland is supported by groundwater inflows from the adjacent upland. Reductions in the flow rate of the Fort Lyon canal will probably reduce groundwater inflows and may therefore lower water levels and cause a decline in the size of the Arch wetland;

6) Although reduced flow in the Fort Lyon canal may decrease water table levels, it is nevertheless recommended that the proposed new administration building be located in an upland area where the water table is at a greater depth than the currently proposed location.

7) Future work related to the problem of basement flooding at Bent's Old Fort should focus on obtaining the data needed to better understand the causes of flooding and design an appropriate remediation strategy. A newly funded project, with Dr. Woods as Principal Investigator, is focusing on a more detailed characterization of the groundwater hydrology in the vicinity of the Fort, and attempting to assess the changes in groundwater flow that could occur over a range of different hydrologic conditions.

ACKNOWLEDGEMENTS

This study would not have been possible without the support and cooperation of National Park Service staff at Bent's Old Fort National Historical Site, particularly Nancy Keohane, Karl Zimmerman and Dave Hall. The water quality sampling was conducted by Don Campbell of the U.S. Geological Survey. Thomas Ley of the Colorado Division of Water Resources in Pueblo, Colorado kindly provided provisional streamflow data for the Arkansas River and the Fort Lyon storage canal. We are most grateful to Kathy Tonnessen for initiating and supporting this work under contract number CA 1200-99-009 CSU-23 (CSU 5-3 2894).

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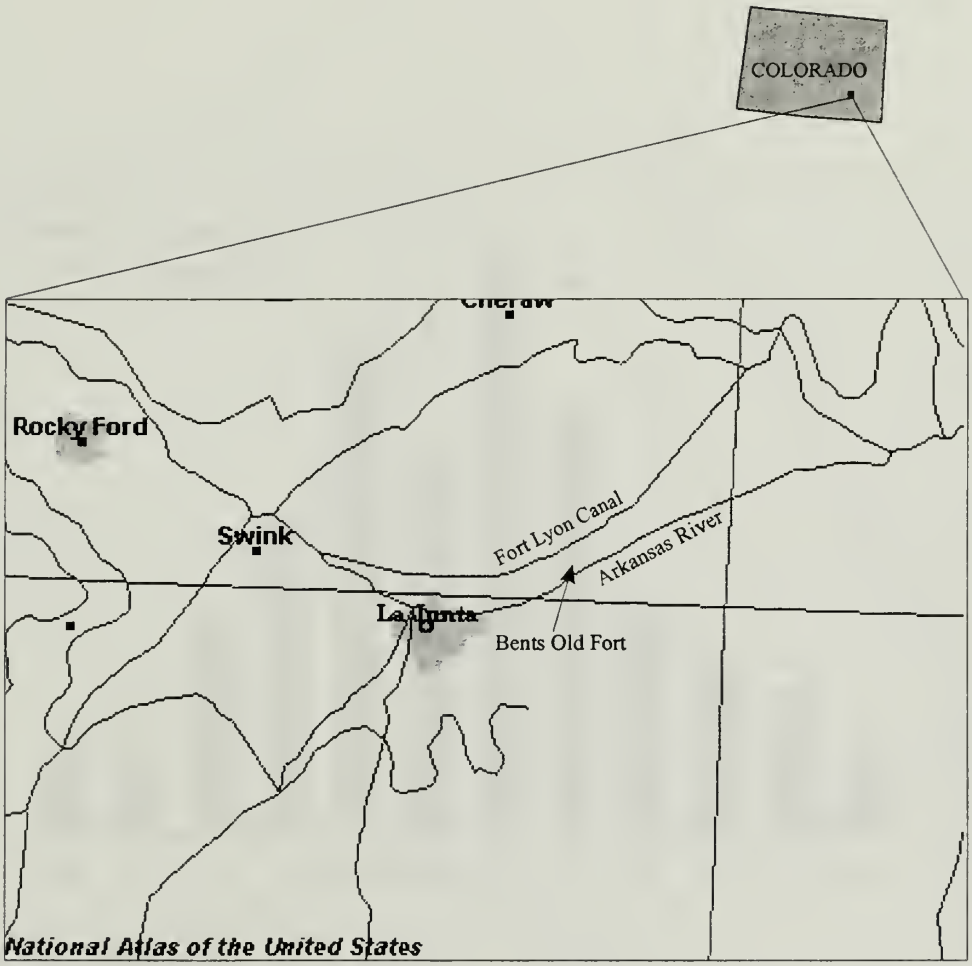

Figure 1. Location of Bents Old Fort in southeastern Colorado. Solid lines indicate streams, rivers and diversion canals.

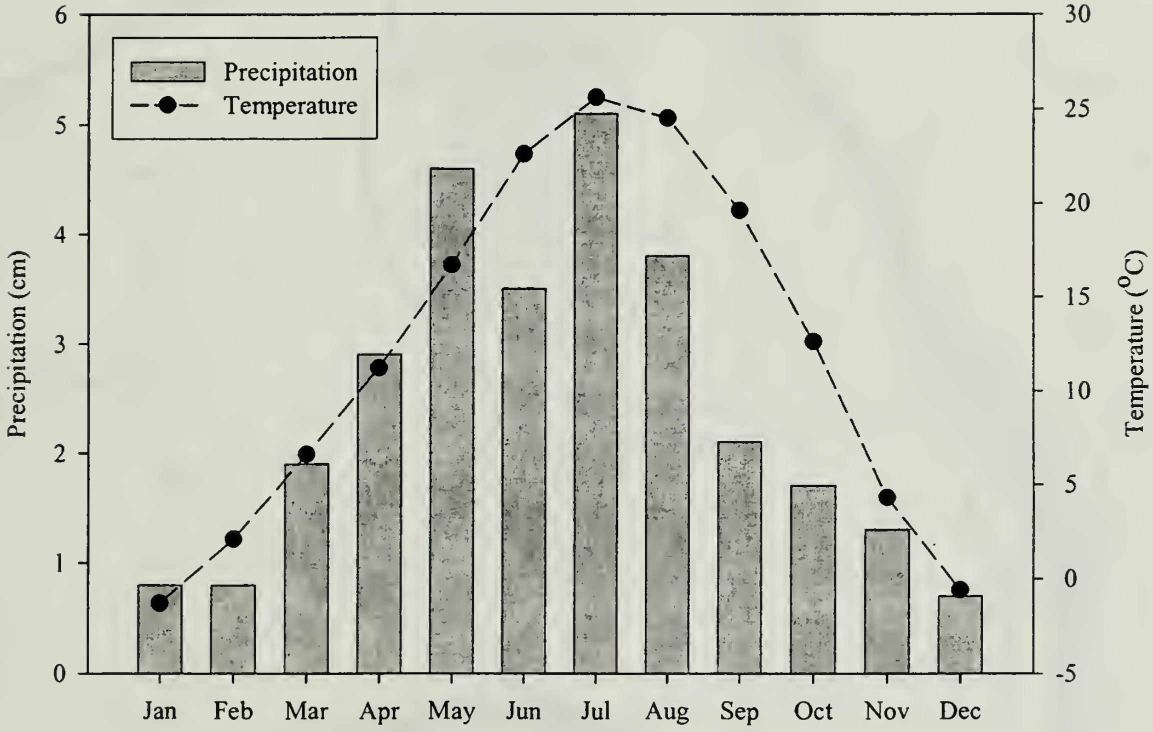

Figure 2. Monthly mean precipitation and temperature for 1945-2001 at La Junta, Colorado.

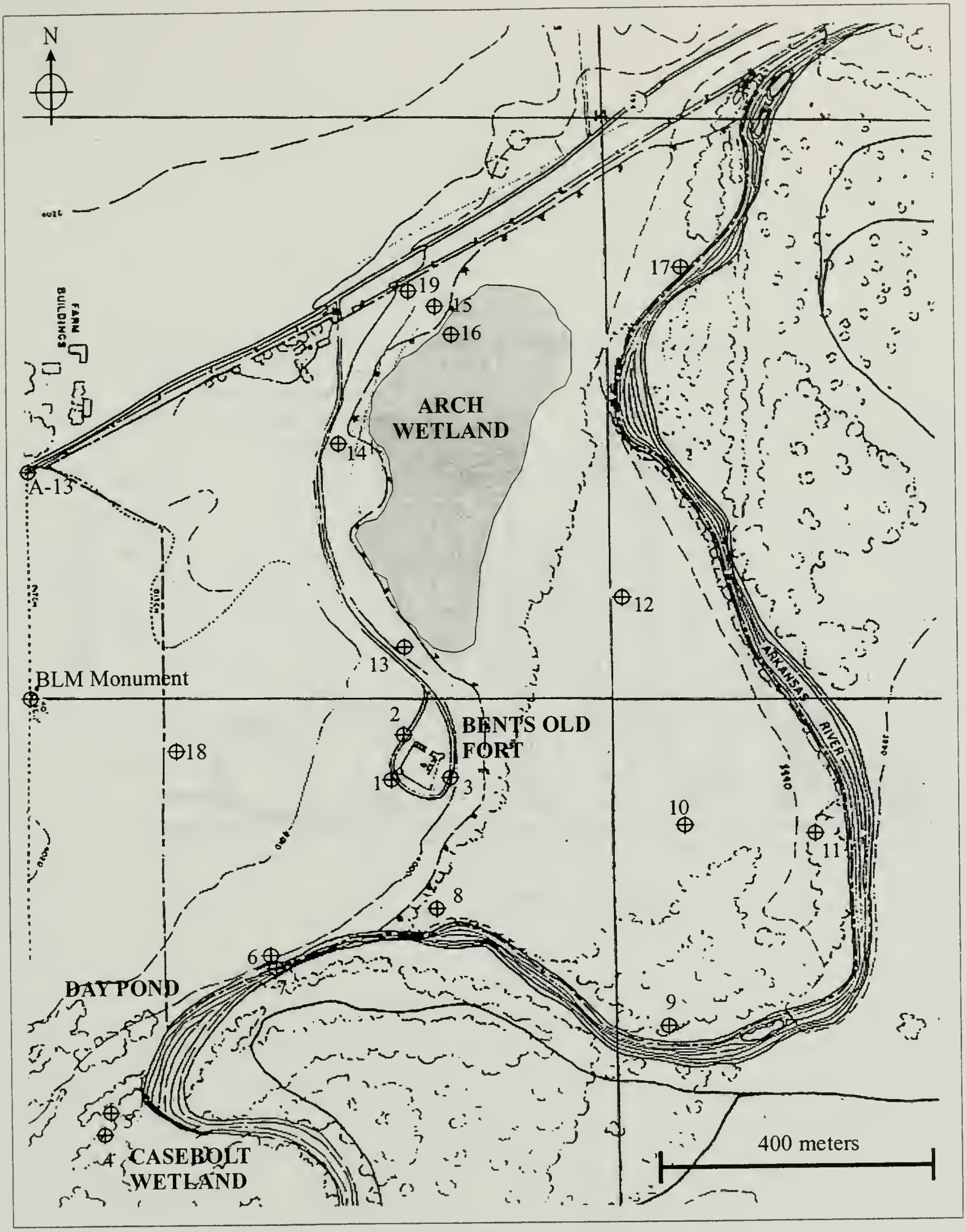

Figure 3. Map of wells and staff gages (numbered 1 –19) and survey benchmarks (BLM and A-13) at Bents Old Fort, Colorado.

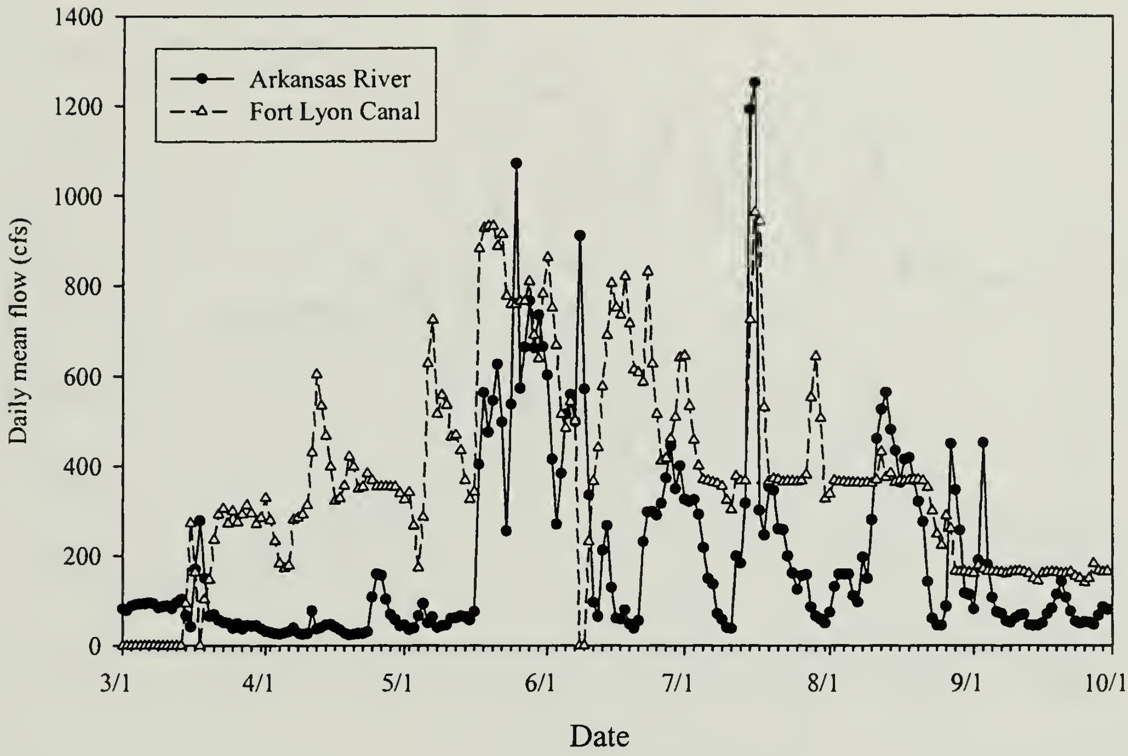

Figure 4. Mean daily flow of the Arkansas River at La Junta (USGS gage no. 07123000) and the Fort Lyon Canal, 1 March – 30 September 2001.

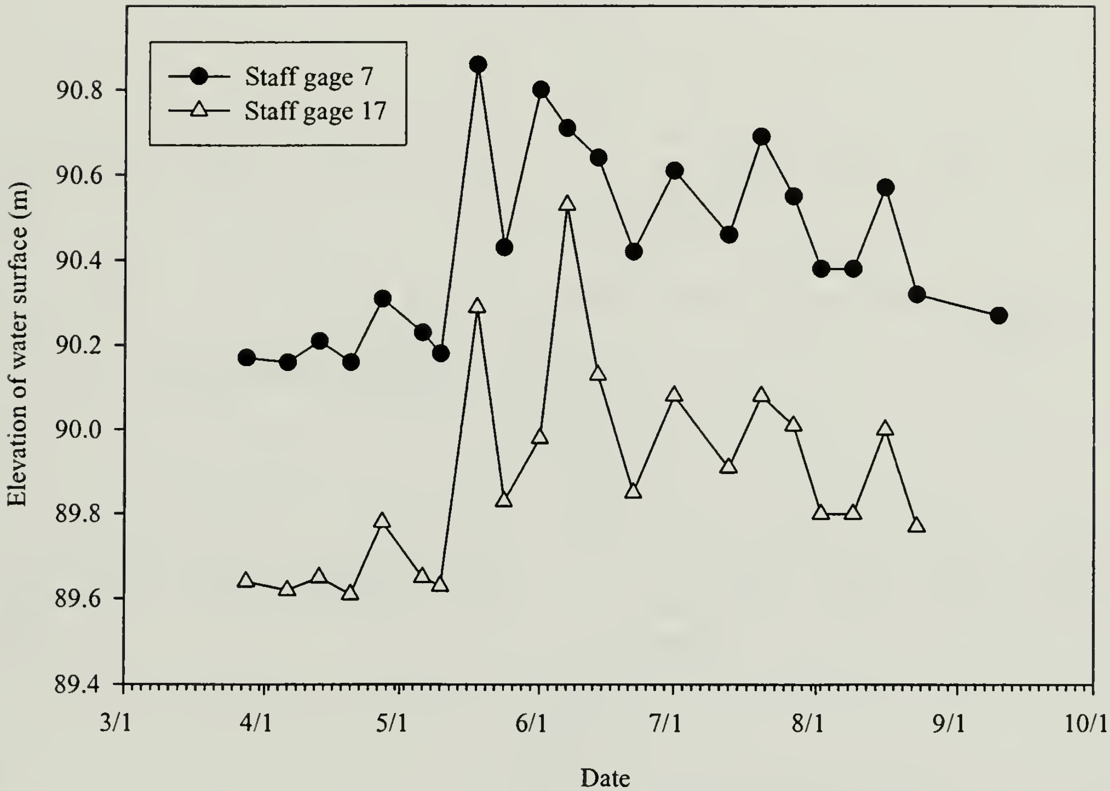

Figure 5. Stage of the Arkansas River at staff gages 7 and 17 at Bents Old Fort, March – September 2001.

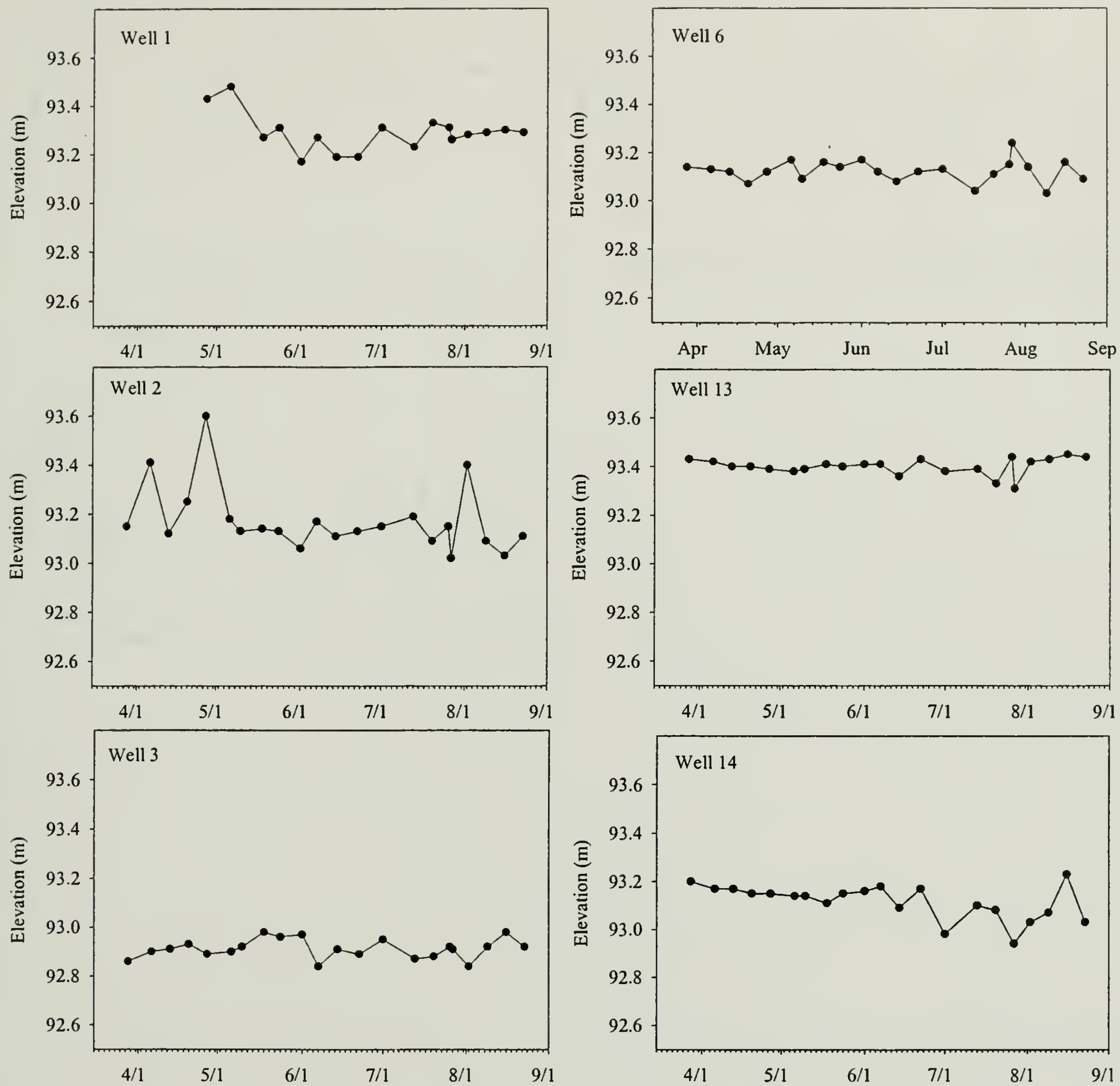

Figure 6. Water levels in upland wells 1-3, 6, 13 and 14 at Bents Old Fort.

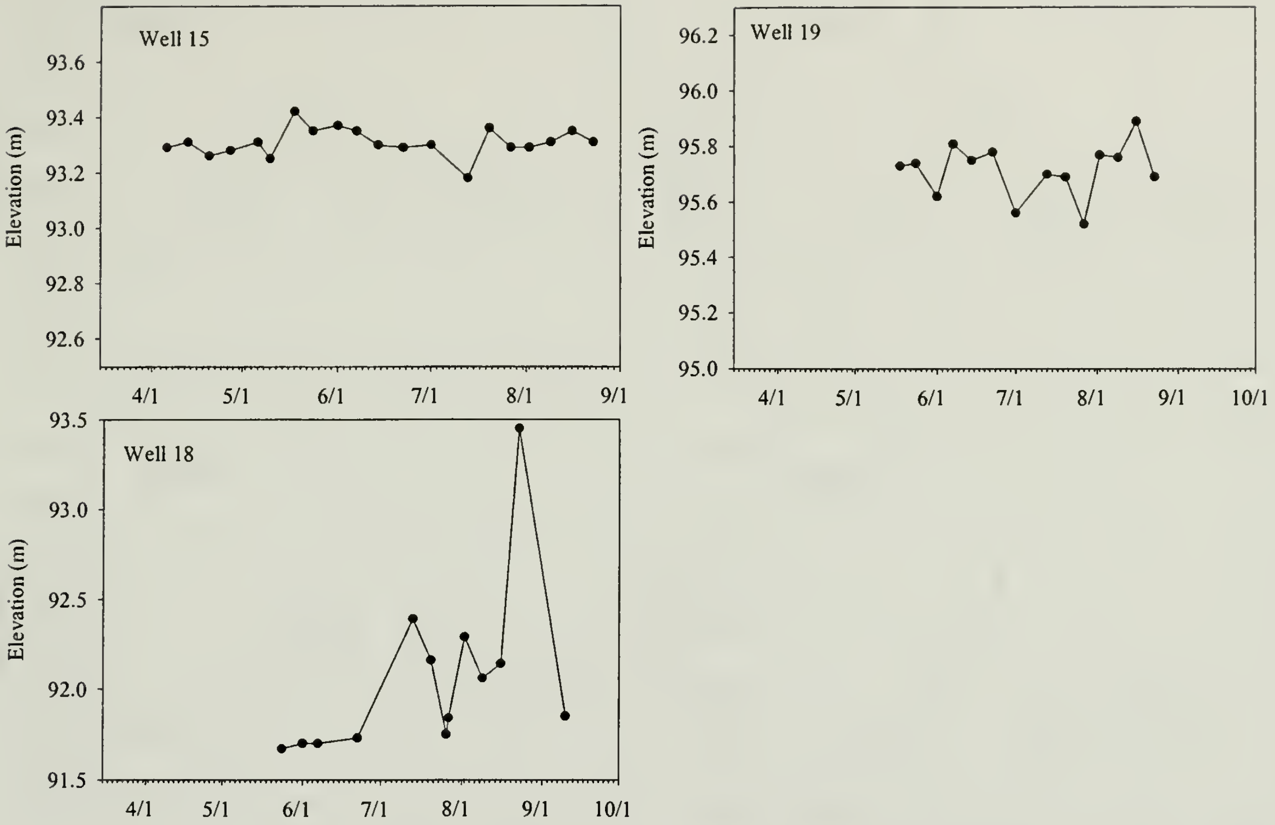

Figure 6 (continued). Water levels in upland wells 15, 18 and 19 at Bents Old Fort. Note the larger vertical scale for well 18.

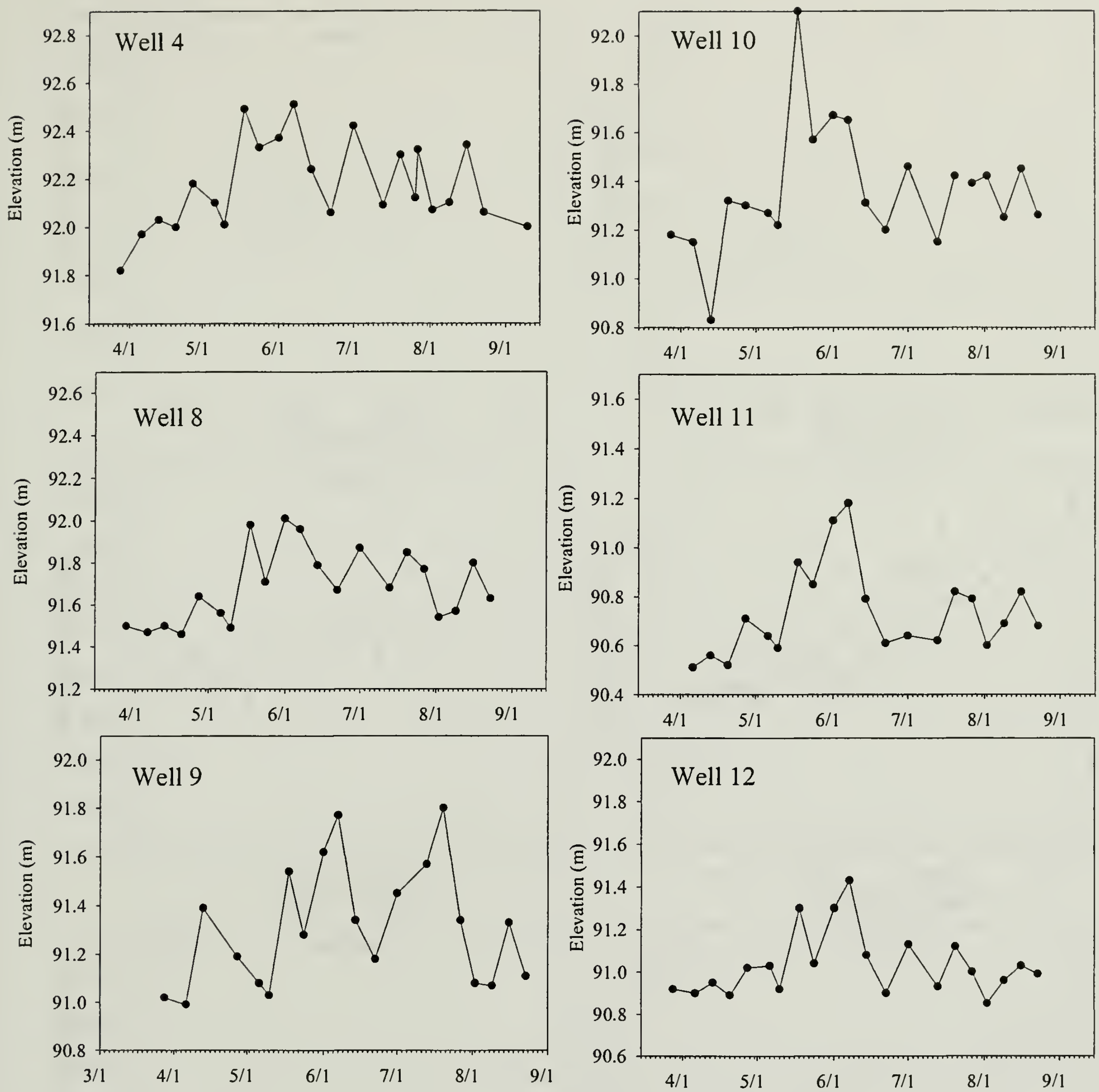

Figure 7. Water levels in floodplain wells 4, and 8 - 12 at Bents Old Fort.

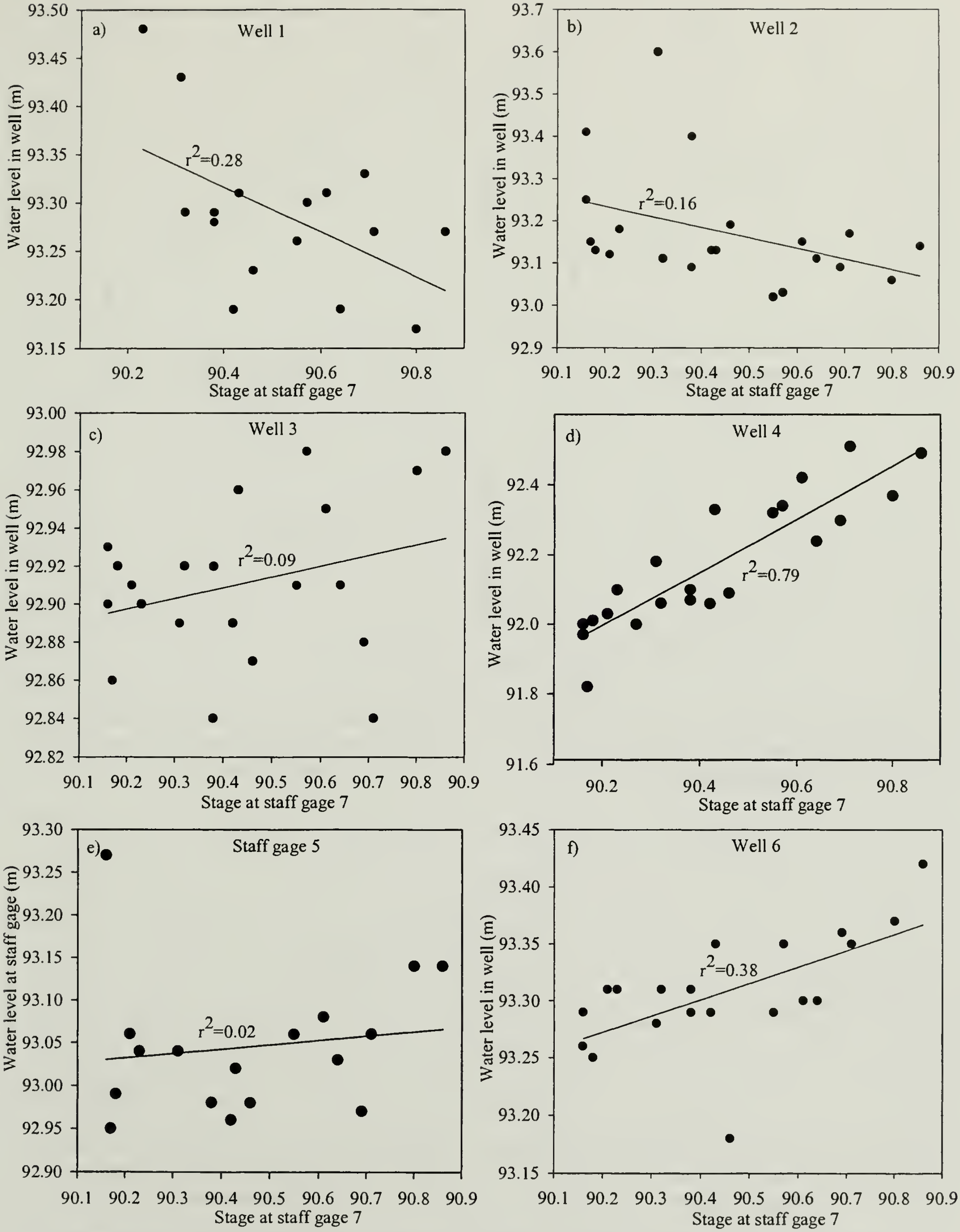

Figure 8. Linear regression of water level versus stage of the Arkansas River at staff gage 7 for wells 1-4, staff gage 5 and well 6. Wells 1-3 are upland wells while wells 4 and 6 are floodplain wells. Staff gage 5 is in the Casebolt wetland.

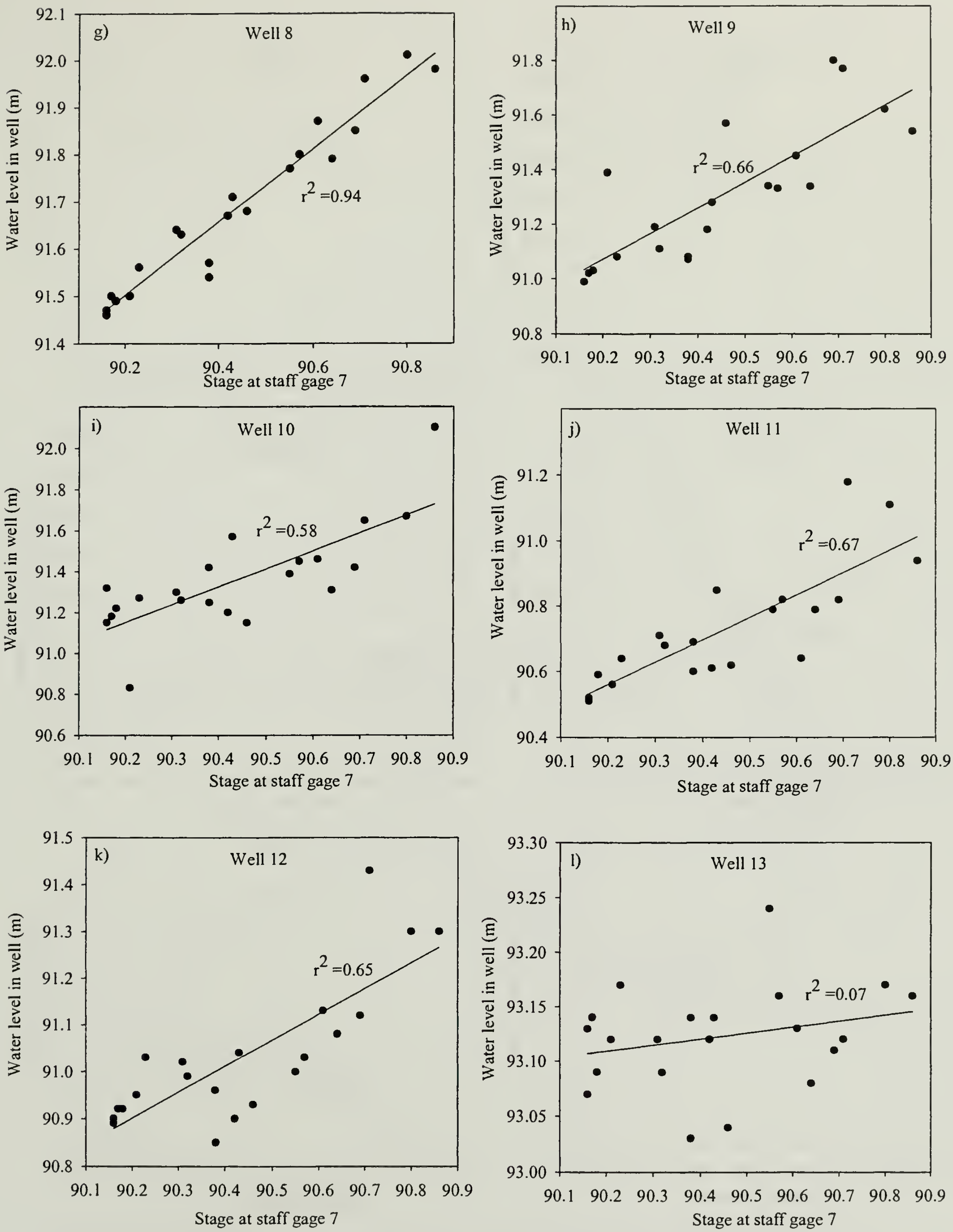

Figure 8 (continued). Linear regression of water level versus stage of Arkansas River at staff gage 7 for wells 8 through 13. Wells 8-13 are floodplain wells while well 13 is an upland well.

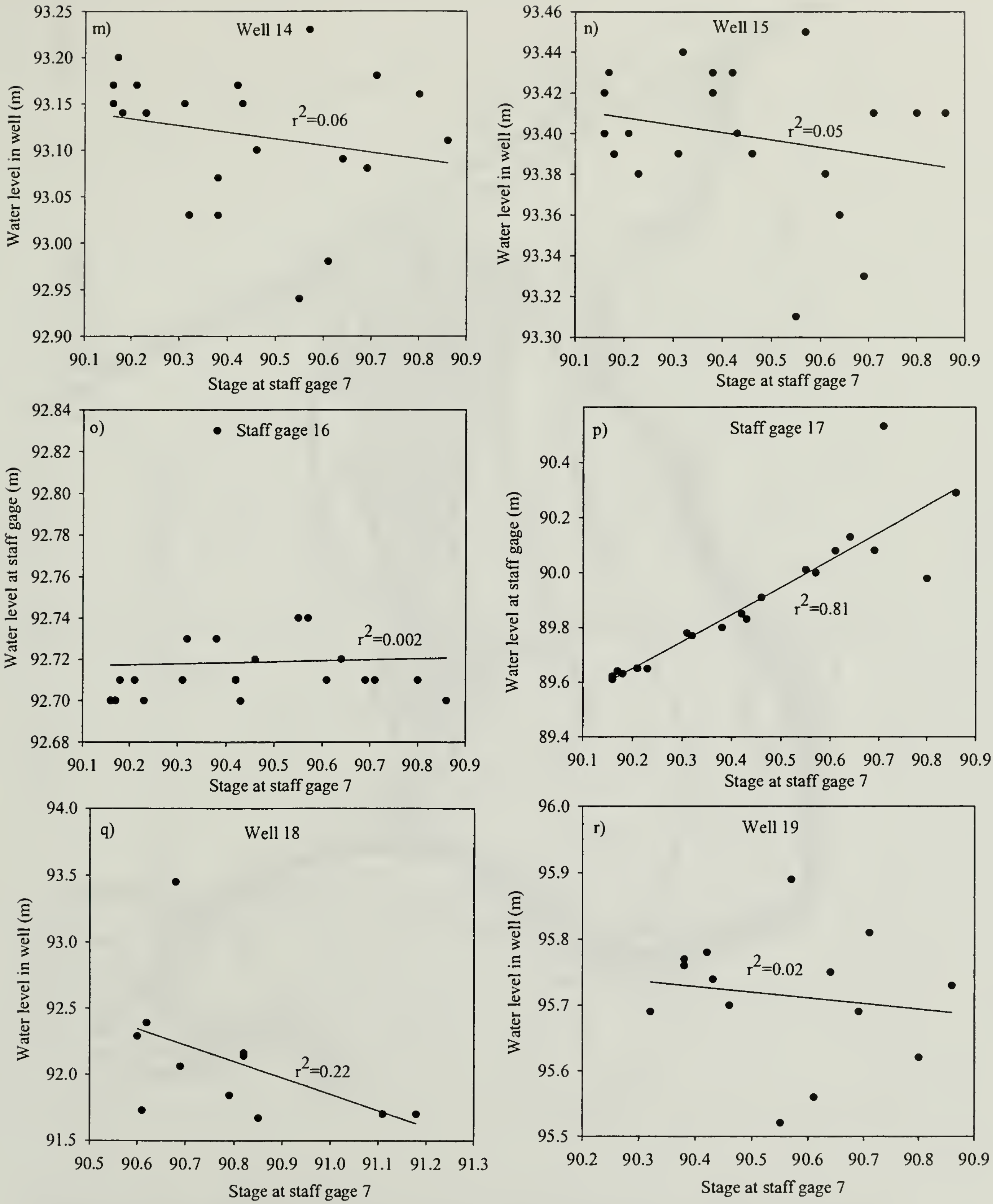

Figure 8 (continued). Linear regression of water level versus stage of Arkansas River at staff gage 7 for wells 14 and 15, staff gages 16 and 17 and wells 18 and 19. Wells 14, 15, 18 and 19 are upland wells. Staff gages 16 and 17 are in the Arch wetland and Arkansas River respectively.

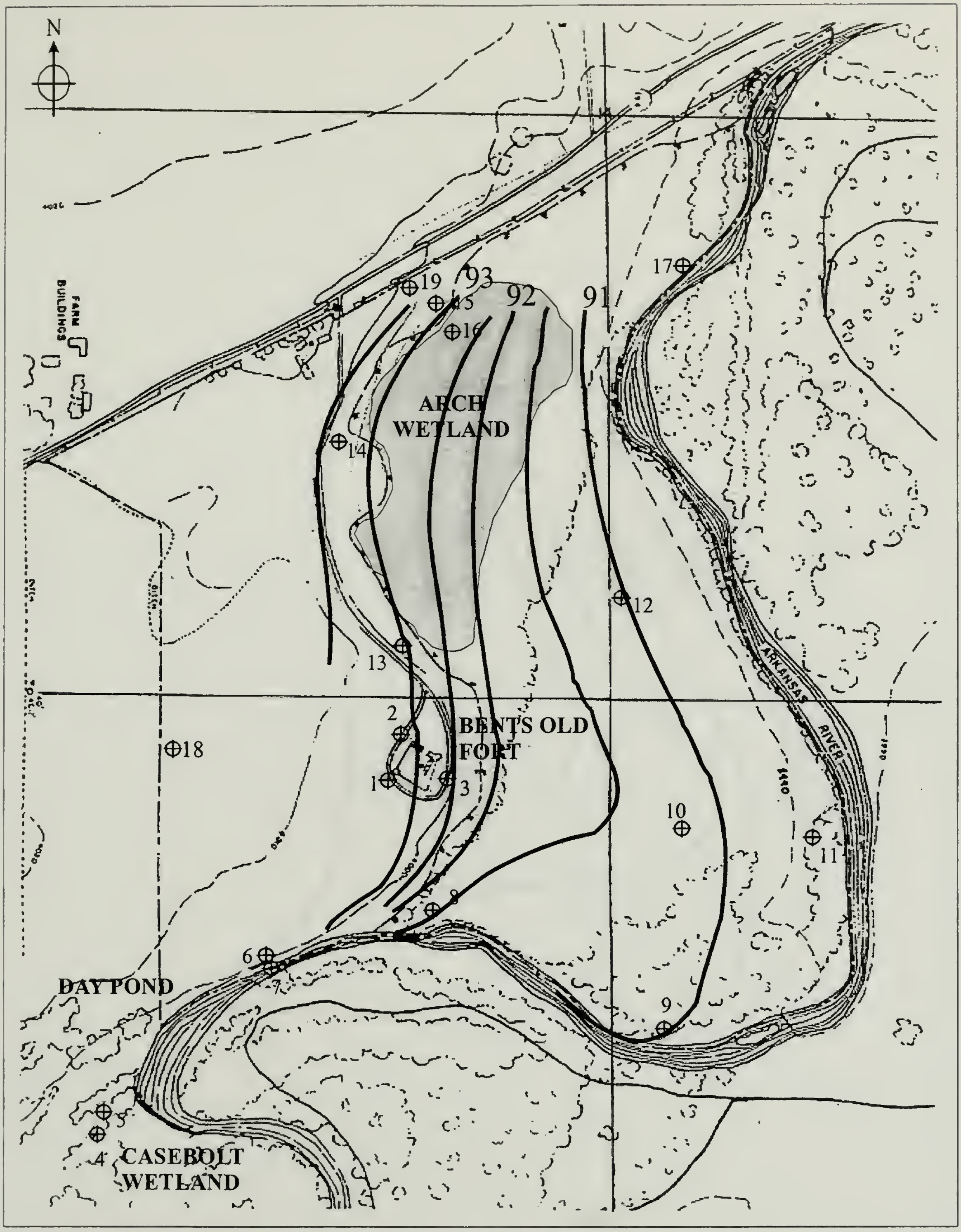

Figure 9. Water table map for Bents Old Fort NHS based on water level data collected 27 April 2001. Thick black lines indicate water table contours in 0.5 meter increments.

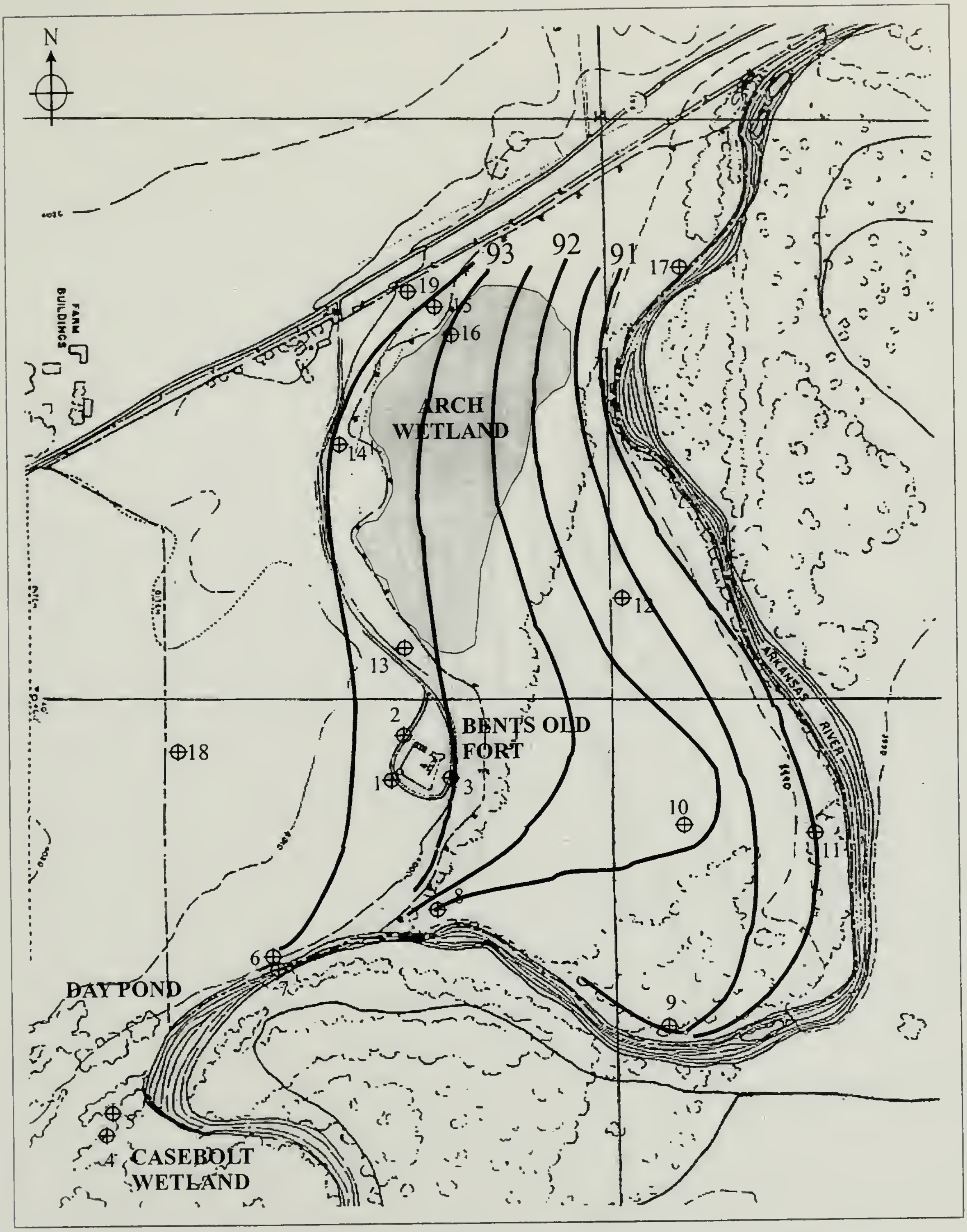

Figure 10. Water table map for Bents Old Fort NHS based on water level data collected 15 May 2001. Thick black lines indicate water table contours in 0.5 meter increments.

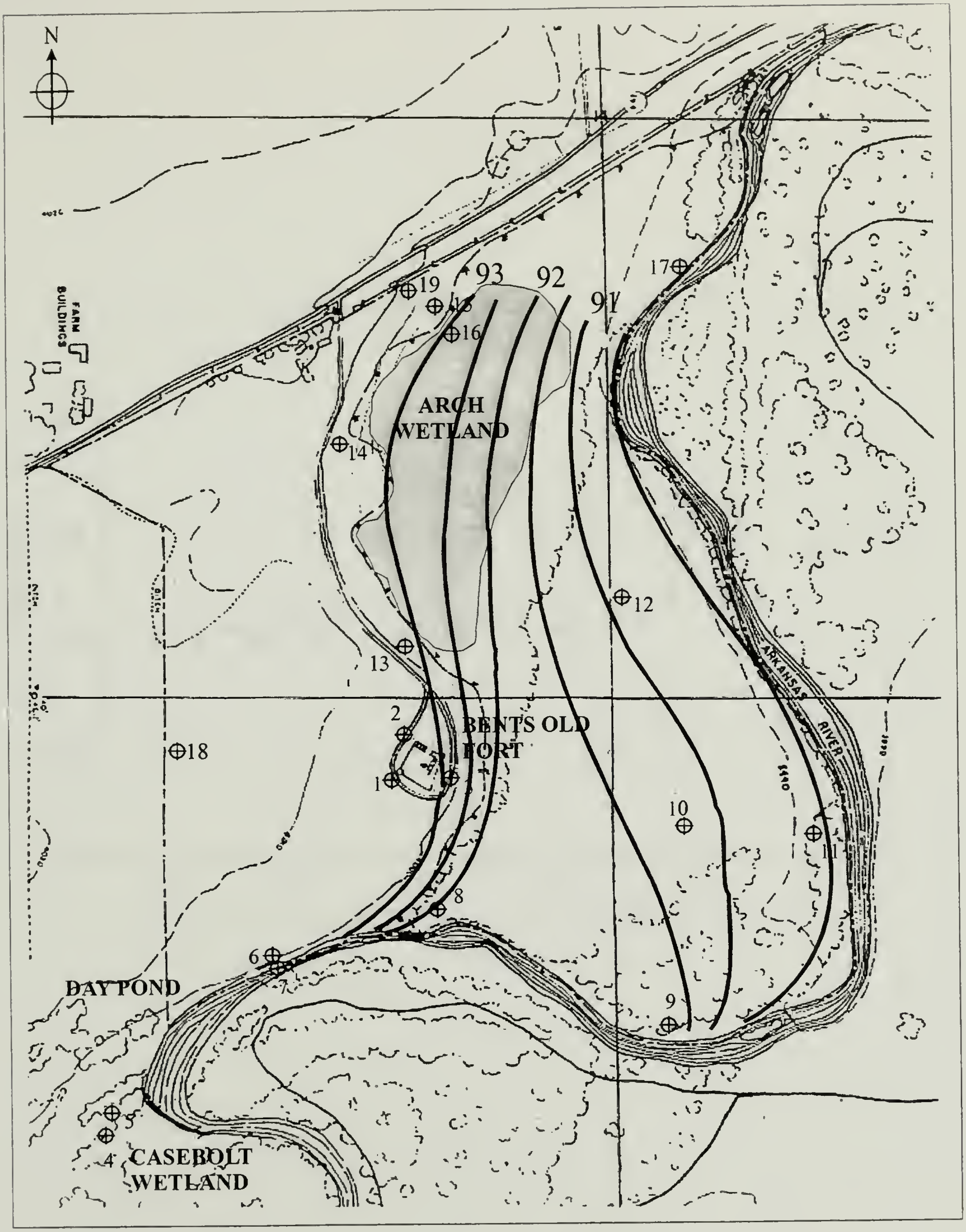

Figure 11. Water table map for Bents Old Fort NHS based on water level data collected 13 July 2001. Thick black lines indicate water table contours in 0.5 meter increments.

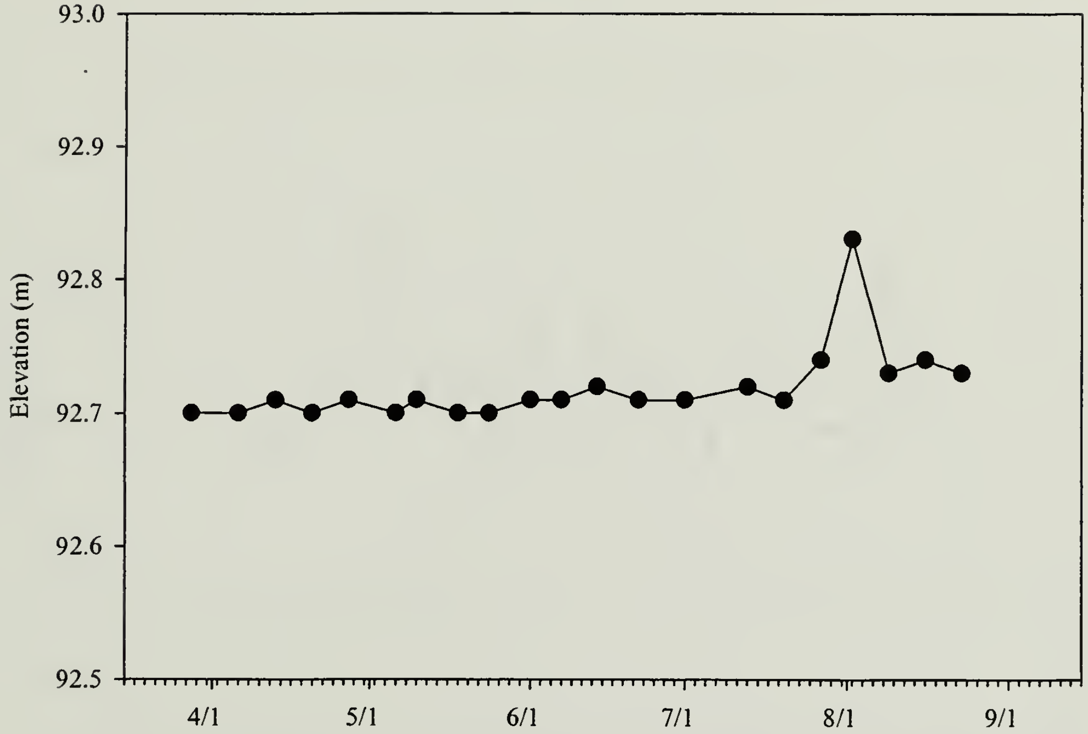

Figure 12. Water levels in the Arch wetland as measured at staff gage 16, March – September 2001.

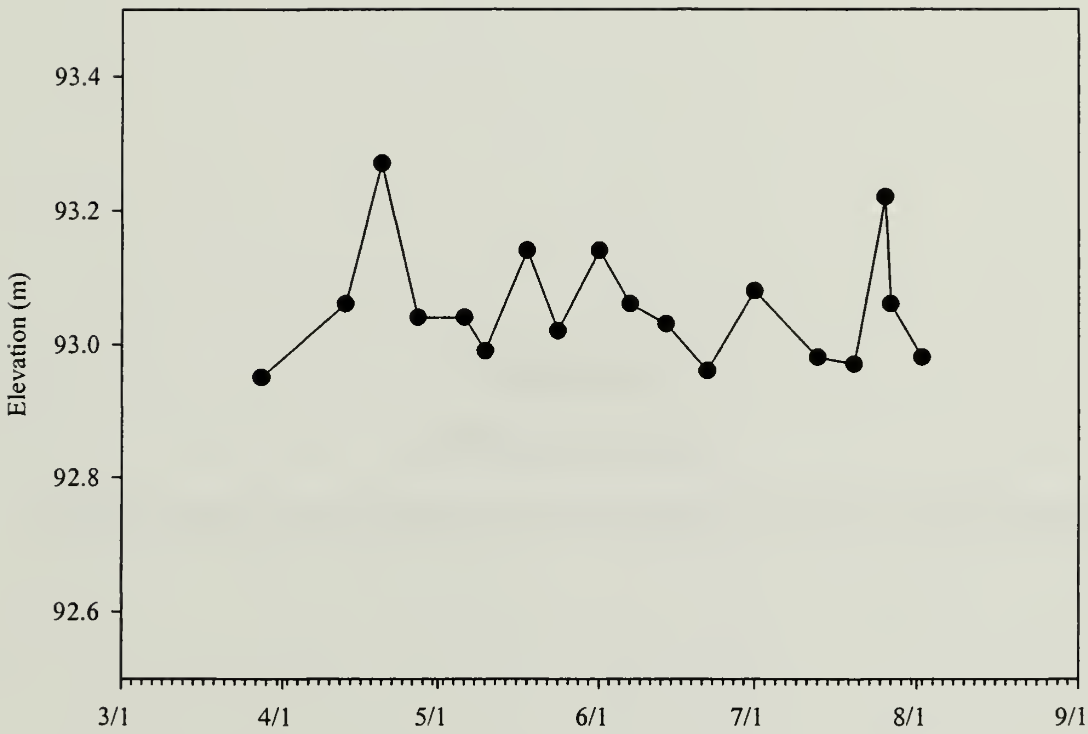

Figure 13. Water levels in the Casebolt wetland as measured at staff gage 5, March – September 2001.

APPENDIX A

HYDROLOGIC DATA

(WATER LEVELS IN METERS ELEVATION RELATIVE TO LOCAL DATUM)

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
03/28/01		93.15	92.86	91.82	92.95		90.17	91.50	91.02	91.18		90.92	93.14	93.43	93.20	92.70	89.64		
04/06/01		93.41	92.90	91.97		93.29	90.16	91.47	90.99	91.15	90.51	90.90	93.13	93.42	93.17	92.70	89.62		
04/13/01		93.12	92.91	92.03	93.06	93.31	90.21	91.50	91.39	90.83	90.56	90.95	93.12	93.40	93.17	92.71	89.65		
04/20/01		93.25	92.93	92.00	93.27	93.26	90.16	91.46		91.32	90.52	90.89	93.07	93.40	93.15	92.70	89.61		
04/27/01	93.43	93.60	92.89	92.18	93.04	93.28	90.31	91.64	91.19	91.30	90.71	91.02	93.12	93.39	93.15	92.71	89.78		
05/06/01	93.48	93.18	92.90	92.10	93.04	93.31	90.23	91.56	91.08	91.27	90.64	91.03	93.17	93.38	93.14	92.70	89.65		95.73
05/10/01		93.13	92.92	92.01	92.99	93.25	90.18	91.49	91.03	91.22	90.59	90.92	93.09	93.39	93.14	92.71	89.63		95.74
05/18/01	93.27	93.14	92.98	92.49	93.14	93.42	90.86	91.98	91.54	92.10	90.94	91.30	93.16	93.41	93.11	92.70	90.29		95.62
05/24/01	93.31	93.13	92.96	92.33	93.02	93.35	90.43	91.71	91.28	91.57	90.85	91.04	93.14	93.40	93.15	92.70	89.83	91.67	95.81
06/01/01	93.17	93.06	92.97	92.37	93.14	93.37	90.80	92.01	91.62	91.67	91.11	91.30	93.17	93.41	93.16	92.71	89.98	91.70	95.75
06/07/01	93.27	93.17	92.84	92.51	93.06	93.35	90.71	91.96	91.77	91.65	91.18	91.43	93.12	93.41	93.18	92.71	90.53	91.70	95.78
06/14/01	93.19	93.11	92.91	92.24	93.03	93.30	90.64	91.79	91.34	91.31	90.79	91.08	93.08	93.36	93.09	92.72	90.13		95.56
06/22/01	93.19	93.13	92.89	92.06	92.96	93.29	90.42	91.67	91.18	91.20	90.61	90.90	93.12	93.43	93.17	92.71	89.85	91.73	95.70
07/01/01	93.31	93.15	92.95	92.42	93.08	93.30	90.61	91.87	91.45	91.46	90.64	91.13	93.13	93.38	92.98	92.71	90.08		95.69
07/13/01	93.23	93.19	92.87	92.09	92.98	93.18	90.46	91.68	91.57	91.15	90.62	90.93	93.04	93.39	93.10	92.72	89.91	92.39	
07/20/01	93.33	93.09	92.88	92.30	92.97	93.36	90.69	91.85	91.80	91.42	90.82	91.12	93.11	93.33	93.08	92.71	90.08	92.16	95.52
07/26/01	93.31	93.15	92.92	92.12	93.22								93.15	93.44				91.75	95.77
07/27/01	93.26	93.02	92.91	92.32	93.06	93.29	90.55	91.77	91.34	91.39	90.79	91.00	93.24	93.31	92.94	92.74	90.01	91.84	95.76
08/02/01	93.28	93.40	92.84	92.07	92.98	93.29	90.38	91.54	91.08	91.42	90.60	90.85	93.14	93.42	93.03	92.83	89.80	92.29	95.89
08/09/01	93.29	93.09	92.92	92.10		93.31	90.38	91.57	91.07	91.25	90.69	90.96	93.03	93.43	93.07	92.73	89.80	92.06	95.69
08/16/01	93.30	93.03	92.98	92.34		93.35	90.57	91.80	91.33	91.45	90.82	91.03	93.16	93.45	93.23	92.74	90.00	92.14	
08/23/01	93.29	93.11	92.92	92.06		93.31	90.32	91.63	91.11	91.26	90.68	90.99	93.09	93.44	93.03	92.73	89.77	93.45	
09/10/01				92.00			90.27											91.85	

APPENDIX B

WATER QUALITY DATA

STATION NUMBER	STATION NAME	STATION NUMBER	DATE	TIME	RECORD NUMBER	DIS-CHARGE, INST. CUBIC FEET PER SECOND (00061)
380214103260200	DAY POND AT FORT BENT NHS NR HADLEY CO	380214103260200	03-27-01	1530	00101995	--
380208103260500	ARKANSAS R NR DAY POND AT FT BENT NHS NR HADLEY CO	380208103260500	03-27-01	1602	00101996	--
380243103254800	WETLAND NR DAR ARCH AT FORT BENT NHS NR HADLEY CO	380243103254800	03-27-01	1620	00101998	--
380249103253600	OUTFLO FRM WETLAND NR DAR ARCH AT FT BENT NHS CO	380249103253600	03-27-01	1705	00101999	--
380249103253600	OUTFLO FRM WETLAND NR DAR ARCH AT FT BENT NHS CO	380249103253600	03-27-01	1710	00102000	--
380208103260500	ARKANSAS R NR DAY POND AT FT BENT NHS NR HADLEY CO	380208103260500	07-31-01	0950	00105402	--
380209103260700	CASEBOLT WETLAND AT FORT BENT NHS, CO	380209103260700	07-31-01	1005	00105400	--
380214103260200	DAY POND AT FORT BENT NHS NR HADLEY CO	380214103260200	07-31-01	1045	00105403	--
380252103253400	MAIN IRR. DITCH NR ARKANSAS R.,FORT BENT NHS, CO	380252103253400	07-31-01	1340	00108407	--
380252103254000	IRRIGATION DITCH NO. 5, FORT BENT NHS,CO	380252103254000	07-31-01	1355	00108409	.80
380243103254800	WETLAND NR DAR ARCH AT FORT BENT NHS NR HADLEY CO	380243103254800	07-31-01	1410	00105401	--
380238103260200	SC02305414CCB	380238103260200	07-31-01	1610	00105399	--
380238103260200	SC02305414CCB	380238103260200	07-31-01	1615	00108408	--
380240103260700	MAIN IRRIGATION DITCH, NW CORNER FORT BENT NHS, CO	380240103260700	07-31-01	1700	00108406	.20

STATION NUMBER	TUR-BID-ITY (NTU) (00076)	TURBID-ITY LAB HACH 2100AN (NTU) (99872)	OXYGEN, DIS-SOLVED (MG/L) (00300)	PH WATER WHOLE FIELD (STAND-ARD UNITS) (00400)	PH WATER WHOLE LAB (STAND-ARD UNITS) (00403)	SPE-CIFIC CON-DUCT-ANCE LAB (US/CM) (90095)	SPE-CIFIC CON-DUCT-ANCE (US/CM) (00095)	TEMPER-ATURE WATER (DEG C) (00010)	CALCIUM DIS-SOLVED (MG/L AS CA) (00915)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG) (00925)	POTAS-SIUM, DIS-SOLVED (MG/L AS K) (00935)	SODIUM, DIS-SOLVED (MG/L AS NA) (00930)
380214103260200	6.2	--	9.8	8.6	8.0	1650	1720	9.8	172	63.9	2.18	107
380208103260500	40	--	7.9	8.6	8.1	2050	2120	13.9	217	74.1	5.64	162
380243103254800	3.9	--	9.9	8.3	7.7	1430	1500	13.4	135	39.5	2.70	83.0
380249103253600	30	--	8.5	8.4	7.9	1460	1490	6.2	144	40.0	4.26	85.2
380249103253600	25	--	8.5	8.4	7.8	1430	1490	6.2	141	39.1	3.70	81.5
380208103260500	--	490	7.2	8.8	8.1	1630	1660	22.8	163	53.3	4.88	120
380209103260700	--	37	--	--	7.3	1660	1540	22.1	163	61.9	17.4	106
380214103260200	--	510	5.4	8.5	8.3	1320	2040	22.5	134	44.2	4.56	87.3
380252103253400	--	340	6.5	9.0	8.1	1330	1490	31.4	138	45.1	4.77	87.2
380252103254000	--	22	6.5	9.0	7.8	1920	1500	30.8	226	78.5	2.66	133
380243103254800	--	8.1	3.1	7.9	7.4	1490	1340	21.2	166	46.6	4.22	102
380238103260200	--	3.5	5.5	8.6	8.1	1830	1850	24.7	2.19	1.65	2.83	407
380238103260200	--	13	--	--	8.1	1830	--	--	1.73	1.62	2.84	408
380240103260700	--	430	6.9	9.0	7.5	1200	1270	27.5	125	39.9	7.18	76.1

STATION NUMBER	ANC UNFLTRD TIT 4.5 LAB (MG/L AS CACO3) (90410)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL) (00940)	FLUO-RIDE, DIS-SOLVED (MG/L AS F) (00950)	SILICA, DIS-SOLVED (MG/L AS SIO2) (00955)	SULFATE DIS-SOLVED (MG/L AS SO4) (00945)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L) (70300)	NITRO-GEN, AMMONIA DIS-SOLVED (MG/L AS N) (00608)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N) (00625)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N) (00631)	NITRO-GEN, NITRITE DIS-SOLVED (MG/L AS N) (00613)	PHOS-PHORUS DIS-SOLVED (MG/L AS P) (00666)	PHOS-PHORUS ORTHO, DIS-SOLVED (MG/L AS P) (00671)
380214103260200	211	32.0	1.9	13.7	687	1330	E.038	.33	1.14	.018	<.060	<.018
380208103260500	220	61.1	1.1	12.6	859	1670	.052	.50	3.26	.027	.063	.072
380243103254800	195	29.4	1.2	14.5	555	1120	<.041	.37	2.20	.041	<.060	E.011
380249103253600	206	31.4	1.4	9.1	545	1120	<.041	.30	E.028	<.006	<.060	.028
380249103253600	206	30.2	1.3	9.3	545	1100	<.041	.27	<.047	<.006	<.060	.026
380208103260500	187	48.0	1.1	12.3	663	1290	E.029	1.2	2.16	.007	.079	.087
380209103260700	171	36.2	1.7	7.9	683	1270	3.28	5.6	E.028	E.005	.072	<.020
380214103260200	150	30.7	1.0	10.7	530	1000	<.040	1.0	1.99	.014	E.041	.045
380252103253400	148	30.9	1.0	10.7	525	994	E.025	1.6	1.80	.019	E.050	.047
380252103254000	211	36.9	2.0	22.9	892	1660	.224	.66	1.04	.043	<.060	<.020
380243103254800	218	31.9	1.5	18.2	577	1150	.075	.48	.893	.058	<.060	E.011
380238103260200	428	29.2	2.1	9.5	466	1190	E.031	<.08	.496	<.006	.071	.062
380238103260200	428	29.1	2.1	9.7	466	1190	E.033	<.08	.491	<.006	.076	.068
380240103260700	125	27.2	.8	9.4	477	882	E.025	3.5	1.82	.040	.080	.045

STATION NUMBER	PHOS-PHORUS TOTAL (MG/L AS P) (00665)	ALUM-INUM, DIS-SOLVED (UG/L AS AL) (01106)	BARIUM, DIS-SOLVED (UG/L AS BA) (01005)	CADMIUM DIS-SOLVED (UG/L AS CD) (01025)	CHRO-MIUM, DIS-SOLVED (UG/L AS CR) (01030)	COBALT, DIS-SOLVED (UG/L AS CO) (01035)	COPPER, DIS-SOLVED (UG/L AS CU) (01040)	IRON, DIS-SOLVED (UG/L AS FE) (01046)	LITHIUM DIS-SOLVED (UG/L AS LI) (01130)	MANGA-NESE, DIS-SOLVED (UG/L AS MN) (01056)	MOLYB-DENUM, DIS-SOLVED (UG/L AS MO) (01060)	NICKEL, DIS-SOLVED (UG/L AS NI) (01065)
380214103260200	<.060	--	--	--	--	--	--	--	--	--	--	--
380208103260500	.151	--	--	--	--	--	--	--	--	--	--	--
380243103254800	E.052	--	--	--	--	--	--	--	--	--	--	--
380249103253600	.121	--	--	--	--	--	--	--	--	--	--	--
380249103253600	.086	--	--	--	--	--	--	--	--	--	--	--
380208103260500	.573	E13	62.7	<8.00	<10.0	<13.0	<5.0	<10	61.9	8.9	<50.0	E1.67
380209103260700	.190	E8	133	<8.00	<10.0	<13.0	<5.0	30	75.1	236	<50.0	6.14
380214103260200	.325	E14	90.6	<8.00	<10.0	<13.0	<5.0	<10	49.1	E2.7	<50.0	<2.00
380252103253400	.612	E14	88.2	<8.00	<10.0	<13.0	<5.0	<10	48.0	E2.3	<50.0	E1.59
380252103254000	<.060	15	37.0	<8.00	<10.0	<13.0	<5.0	<10	74.2	10.4	<50.0	<2.00
380243103254800	E.059	<15	30.0	<8.00	<10.0	<13.0	<5.0	40	59.4	101	<50.0	<2.00
380238103260200	.075	E10	9.0	<8.00	<10.0	<13.0	5.6	30	207	<3.0	<50.0	<5.00
380238103260200	.078	<15	8.9	<8.00	<10.0	<13.0	6.9	20	208	<3.0	<50.0	<2.00
380240103260700	.844	E14	83.4	<8.00	<10.0	<13.0	E2.6	M	43.1	21.1	<50.0	E2.36

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY PROCESS DATE 2-04-02
MULTIPLE STATION ANALYSES

STATION NUMBER	SELENIUM, DISSOLVED (UG/L AS SE) (01145)	SILVER, DISSOLVED (UG/L AS AG) (01075)	STRONTIUM, DISSOLVED (UG/L AS SR) (01080)	VANADIUM, DISSOLVED (UG/L AS V) (01085)	ZINC, DISSOLVED (UG/L AS ZN) (01090)
380214103260200	--	--	--	--	--
380208103260500	--	--	--	--	--
380243103254800	--	--	--	--	--
380249103253600	--	--	--	--	--
380249103253600	--	--	--	--	--
380208103260500	10.5	<.2	2520	E4.8	<20
380209103260700	3.3	<.2	2930	<8.0	<20
380214103260200	10.2	<.2	1980	E5.4	<20
380252103253400	9.6	<.2	2060	E4.9	<20
380252103254000	10.5	<.2	3970	E5.2	<20
380243103254800	5.6	<.2	2800	<8.0	<20
380238103260200	<2.0	<.2	84.1	<8.0	218
380238103260200	<2.0	<.2	78.8	<8.0	242
380240103260700	8.3	<.2	1890	<8.0	<20

0Remark Codes Used in This report:
< -- Less than
E -- Estimated value
0Null Value Remark Codes Used in This Report:
M -- Presence verified, not quantified